Environmental Effects on Cotton Fiber Carbohydrate Concentration and Quality

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) grown in reduced light environments produces inferior fiber compared with that produced in abundant sunlight environments. This response to low light suggests that insufficient photosynthetic assimilates are the cause of the fiber quality reductions. The primary objective of this research was to determine how fiber carbohydrates respond to varying levels of sunlight during development. A field study was conducted from 1995 to 1997 in which cotton was exposed to two light regimes during reproductive growth: (i) incident sunlight and (ii) 70% of incident sunlight achieved with shade cloth. Samples of fiber, ovules, and leaves subtending the boll were collected at 0, 14, 21, and 35 d post anthesis (DPA) and analyzed for starch, glucose, fructose, and sucrose. Fiber quality was determined at the end of the season. With some exceptions, the shade treatment reduced carbohydrates levels in the leaf and ovule tissue. At 14 DPA, starch was reduced 29% in fiber grown under shade. Sucrose levels in shade fiber was reduced 31% at 21 DPA. The carbohydrate reductions at 14 and 21 DPA occurred during a period of fiber development when strength is determined. These carbohydrate reductions parallel the 3% fiber strength reductions seen with low light. The reduced sucrose levels at 21 DPA induced by the shade also occur during fiber secondary cell wall deposition and match the lower fiber micronaire produced under shade. These data present compelling evidence that adequate carbon assimilates are required to produce fiber quality approaching genetic maximums.

S$_{\text{UPERIOR FIBER QUALITY}}$ can make cotton lint more desirable to the textile industry (Deussen, 1992). Consequently, genetic improvements in fiber quality traits by U.S. cotton breeders over the years have given U.S. cotton a somewhat competitive advantage in world cotton markets (Sasser and Shane, 1996). Unfortunately, adverse environmental conditions can have a damping effect and mask any genetic improvements in fiber quality.

A number of environmental factors have been identified that affect fiber quality. The optimal night temperature for development of fiber length was determined to be 15 to 21°C, with shorter fibers developing in growth temperatures outside of that range (Gipson and Joham, 1968, 1969). Micronaire was also reduced when night temperatures were lower than 25°C (Gipson and Joham, 1968). Moisture deficits have been reported to reduce fiber lengths (Bennett et al., 1967; Eaton and Ergle, 1952, 1954; Marani and Amirav, 1971), but the moisture stress needs to be severe and occur shortly after flowering for there to be a significant reduction of the fiber length (Marani and Amirav, 1971). Drought stress can also reduce fiber micronaire (Eaton and Ergle, 1952; Marani and Amirav, 1971), but this effect is probably due to reductions in the photosynthetic capacity of the canopy. This hypothesis is further supported by evidence from shading studies where a 30% shade treatment reduced the micronaire (Pettigrew, 1995, 1996) and a 70% shade treatment reduced fiber maturity, a component of micronaire (Eaton and Ergle, 1954). Fiber micronaire has also been shown to be correlated with leaf photosynthetic rates (Pettigrew and Meredith, 1994). Lower light conditions also impacted fiber strength. Both Eaton and Ergle (1954) and Pettigrew (1995) demonstrated that reduced sunlight conditions resulted in weaker fiber than that produced in normal sunlight.

A great deal of information describing the time course of cotton fiber development and its underlying physiological and biochemical processes has been accumulated. Much of this information has been summarized in the review by DeLanghe (1986). The mechanisms by which the environment interacts with these processes to influence fiber quality are not straightforward. Sucrose produced in the photosynthetic tissue is translocated to the developing cotton fruit through pholem tissue and the funiculus (van Iersel et al., 1995). While much of the sucrose is imported into the fiber via symplastic pathways (Ryser, 1992), there can also be some apoplastic transfer (Buchala, 1987). Once inside the fiber cell, sucrose is cleaved by either invertase or sucrose synthase into glucose and fructose which, after further metabolism, are used for production of cellulose (the primary component of the fiber wall) or other cellular components (Basra et al., 1990). Changes in glucose, fructose, and sucrose concentrations during fiber development have been documented by both Jaquet et al. (1982) and Basra et al. (1990). In general, glucose and fructose concentrations increased during early development and reached a maximum during early fiber secondary wall formation. The sucrose trend was inconsistent between the two studies.

While the changes in levels of glucose, fructose, and sucrose during fiber development are documented, it is not known whether these transient individual sugar levels differ among cotton genotypes of varying fiber properties. In addition, manipulations of plant source-to-sink ratios that might alter these fiber transient sugar levels have not been addressed. The primary objective of this research was to determine how the fiber starch, glucose, fructose, and sucrose levels at various stages of fiber development were altered by different light regimes that were previously shown to alter distinct fiber quality properties in cotton genotypes differing in fiber quality. A secondary objective was to trace how the aforementioned treatments affected the carbohydrate levels in the subtending leaves and ovules of the developing fiber.

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MATERIALS AND METHODS

Field plots of the upland cotton genotypes 'Acala Maxxa', 'MD 51ne', and 'SureGrow 125' were grown on a Bosket fine sandy loam (fine-loamy, mixed, thermic Mollic Hapludalf) near Stoneville, MS, in 1995 to 1997. The genotypes were chosen because they represented a range in fiber quality traits. MD 51ne and SureGrow 125 were bred for the Mississippi Delta region and Acala Maxxa was bred for California. Plots were planted 27 April in 1995, 25 April in 1996, and 2 May in 1997 and consisted of six rows, 7.6 m long spaced 1 m apart. These plots were initially overseeded and then hand-thinned to approximately 81 000 plants ha^{-1} when the plants had produced their first or second true leaf. Each year, the experimental area received 110 kg N ha^{-1} in a preplant application. Recommended insect and weed control methods were employed as needed during the growing season. Plots were furrow-irrigated as needed to minimize the effects of moisture deficit stress.

The experimental design was a randomized complete block with five replicates and a factorial arrangement of genotypes and treatments. A new randomization plan was applied each year. Two levels of sunlight comprised the treatments. The first sunlight treatment was the control, incident sunlight level. The second sunlight treatment was 70% of incident sunlight produced by covering the plants with 30% shade cloth as described in detail previously (Pettigrew, 1995). The shade cloth treatment was imposed at 67, 67, and 62 d after planting (DAP) in 1995, 1996, and 1997, respectively, and continued until harvest.

Approximately 1 wk after installation of the shade treatments, sympodial branch first position white blooms (blooms at anthesis) in plots of all the treatments were tagged with jewelers tags. Tagging white blooms for all treatments on the same day, no more than 1 wk after imposition of the shade treatment, insured that the tagged blooms were of equivalent metabolic and developmental ages for each plot. These tagged fruit and their subtending leaves were harvested at 0, 14, 21, or 35 d post anthesis (DPA). At each harvest, four tagged fruit and subtending leaves were collected per plot at approximately 0900 CDT and stored on ice for transport to the lab. Once at the lab, the fruit samples were immediately separated into their fiber and ovule fractions and the area of the subtending leaves measured. At 0 DPA, there was no discernable fiber fraction to separate. The fiber, ovule, and leaf samples for each plot and each harvest were then frozen and stored at −80°C, lyophilized, ground in liquid nitrogen, and stored at −20°C until subsequent analyses for starch and soluble carbohydrates. The time from sample collection in the field to freezing at −80°C was completed within 1.5 h. Prior to grinding, the dry weights of the lyophilized leaf samples were determined. Dry weights and areas of the subtending leaves were used for calculating specific leaf weights (SLW).

Soluble carbohydrates were extracted from 100 mg of each tissue sample with three successive 12-mL washes of boiling 800 mL L^{-1} ethanol, followed by incubation in a 60°C water bath, and centrifugation at 9400 × g for 10 min. The pellet from these centrifugations was saved for starch analyses, and the three supernatants were pooled and evaporated to dryness with a Zymark TurboVap LV evaporator (Zymark Corp., Hopkinton, MA)[1]. The dried supernatant residue was resuspended in 10 mL of 800 mL L^{-1} ethanol for 15 min in a 60°C water bath. Glucose, fructose, and sucrose were assayed on the resuspended supernatant according to the methods previously described by Hendrix (1993). Starch in the pellets remaining from the hot ethanol extraction of the plant tissue was quantified following digestion with amyloglucosidase for 100 min at 55°C according to procedures described by Hendrix (1993) and Heitholt and Schmidt (1994).

At the end of the season, the remaining tagged bolls in each plot were harvested soon after the bolls had opened. The bolls from each plot were ginned separately. After ginning, the lint was sent to Starlab (Knoxville, TN) for determination of fiber bundle strength, elongation, span lengths, micronaire, fiber maturity, and perimeter.

Statistical analyses were performed by analysis of variance (PROC MIXED, SAS Institute, 1996). Analyses across years were performed considering year as a fixed effect. When statistically important interactions were not detected, genotype means were averaged across years and treatments, and treatment means were averaged across year and genotypes. Significant and meaningful year × treatment and year × genotype interactions were presented by year. Means were separated using an LSD at the $P \leq 0.05$ level.

RESULTS

Differences in environmental conditions among years had potential to alter plant development (Table 1). The 1995 growing season could be considered typical for the Mississippi Delta, both in terms of weather and insect infestations. In 1996, plant bug [*Lygus lineolaris* (Palisot de Beauvois)] infestations that were particularly heavy during early growth damaged many fruiting buds (squares) and caused a large amount of early-season square shed. This situation meant fewer available blooms and probably altered the source-sink relationship of the remaining fruit. Heavy rainfall shortly after planting in 1997 caused significant crusting of the soil surface and reduced the final plant population below the desired level of 81 000 plants ha^{-1}. The reduced plant population may have allowed more light penetration into the crop canopy

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[1] Trade names are necessary to report factually on available data; however the USDA neither guarantees nor warrants the standard of the product or service, and the use of the name by USDA implies no approval of the product or service to the exclusion of others that may also be suitable.

Table 1. Monthly weather summary for 1995 through 1997 at Stoneville, MS.

	Precipitation			Thermal† units			Solar‡ radiation		
	1995	1996	1997	1995	1996	1997	1995	1996	1997
		mm						MJ m^{-2}	
May	79	62	148	262	299	170	–	732	710
June	102	133	106	305	323	295	–	655	670
July	148	84	74	379	380	406	–	672	767
August	36	110	71	415	327	334	–	601	683
September	41	112	56	224	226	268	–	525	562

† [(Max. temp. + Min. temp.)/2] − 15.5°C.
‡ Solar radiation sensor was not functioning properly in 1995.

Table 2. Cotton fiber quality traits (elongation, strength, span length, micronaire, maturity and perimeter) as affected by two light regimes averaged across genotypes and years (1995-1997).

Treatment	Fiber elongation	Fiber strength	Span length		Micronaire	Fiber perimeter	Fiber maturity
			2.5%	50%			
	%	kN m^{-1}	cm			μm	%
Control	7.8	197	2.89	1.47	4.38	48.1	85.1
Shade	7.8	192	2.90	1.47	4.21	47.6	83.6
LSD 0.05	0.2	3	0.02	0.01	0.08	0.8	1.5
$P > F$	0.81	0.01	0.40	0.91	0.01	0.30	0.06

and altered the source-sink relationship of the developing fruit. Therefore, years were considered statistically as fixed effects.

As was previously demonstrated (Pettigrew, 1995; 1996), lowering the light level to 70% of the incident light reduced the quality of the fiber produced (Table 2). Because there was no interaction between treatments, genotypes or years, the treatment means were averaged across genotypes and years. The reduced light conditions produced 3% weaker fiber than was produced under control conditions. Fiber micronaire was also reduced 4% by low light growth conditions. Fiber maturity (a component of micronaire) of fiber produced under low light was numerically lower than the control fiber and was statistically different at the $P = 0.06$ level. None of the other fiber traits were significantly altered by the different light regimes.

The reduced light regime had predictable effects on carbohydrate concentrations in the leaves subtending the tagged Position 1 fruit owing to the well documented light response of photosynthesis. No significant and meaningful interactions among treatments and genotypes were detected. Therefore, treatment means were averaged across genotypes and years. The majority of comparisons between the light regimes showed the control treatment to have greater subtending leaf carbohydrate concentrations (Table 3), which is in agreement with the findings of Zhao and Oosterhuis (1998). Starch

in the subtending leaves grown in the low light regime was significantly lower at all harvest dates and, when averaged across harvest dates, was reduced approximately 52% relative to the control leaves. At 14 DPA, the glucose concentration in the shade leaves was 26% lower than in the control leaves. Glucose was reduced 23% in the shade leaves at 35 DPA as well. Leaf fructose concentrations were significantly different only at 35 DPA when the shade leaves had 23% lower fructose. Leaves from the shade treatment had 33, 21, and 28% lower sucrose levels compared with the control leaves at 0, 14, and 21 DPA, respectively. Similar to the behavior of the carbohydrates, SLW of the leaves in the shade treatment was reduced relative to the control leaves at all harvest dates. Averaged across all harvest dates, SLW of leaves in the shade treatment was 13% lower than the control.

The majority of photosynthetic assimilate partitioned to the developing boll is produced either by the leaf subtending that boll (Ashley, 1972) or the leaf subtending an adjacent position on the same sympodial branch (Horrocks et al., 1978). The majority of this assimilate enters the seed coat through the funiculus and then moves symplastically to either the ovule or the fiber (Ryser, 1992). At the first two harvest dates, the only ovule carbohydrate that was altered by the light regimes was starch (Table 4). Because no interactions were detected between treatments and genotypes, the treatment means were averaged across years and genotypes. Low

Table 3. Cotton leaf carbohydrate concentrations and specific leaf weights (SLW) as affected by two light regimes at various stages of development of the companion position one fruit averaged across genotypes and years (1995–1997).

Treatment	Days post anthesis	Starch	Glucose	Fructose	Sucrose	SLW
		μg mg^{-1}				g m^{-2}
	0					
Control		8.7	2.5	1.2	12.4	52.0
Shade		5.0	2.7	1.4	8.4	45.9
LSD 0.05		1.4	0.4	0.2	1.2	1.8
$P > F$		0.01	0.11	0.16	0.01	0.01
	14					
Control		12.5	3.4	1.1	6.4	48.1
Shade		4.5	2.5	1.1	5.1	42.1
LSD 0.05		5.0	0.5	0.2	1.2	2.2
$P > F$		0.01	0.01	0.56	0.02	0.01
	21					
Control		42.8	4.1	1.1	9.0	49.6
Shade		16.8	3.9	1.1	6.5	41.4
LSD 0.05		11.7	0.8	0.2	1.2	1.8
$P > F$		0.01	0.61	0.64	0.01	0.01
	35					
Control		32.2	7.8	4.3	8.2	46.7
Shade		19.5	6.1	2.6	7.0	40.6
LSD 0.05		10.2	1.4	0.6	2.0	2.0
$P > F$		0.02	0.01	0.01	0.25	0.01

Table 4. Cotton ovule carbohydrate concentrations from position one fruit as affected by two light regimes at various stages of development averaged across genotypes and years (1995–1997).

Treatment	Days post anthesis	Starch	Glucose	Fructose	Sucrose
		μg mg^{-1}			
	0				
Control		80.3	7.6	5.7	67.0
Shade		77.0	7.8	6.3	64.4
LSD 0.05		2.9	0.6	0.5	3.8
$P > F$		0.03	0.58	0.06	0.18
	14				
Control		353.5	26.2	28.7	11.1
Shade		317.9	26.8	29.3	11.1
LSD 0.05		12.4	1.8	1.7	1.5
$P > F$		0.01	0.50	0.50	0.95
	21				
Control		210.3	13.3	17.5	20.6
Shade		212.6	14.6	18.4	16.5
LSD 0.05		13.6	1.1	1.2	1.6
$P > F$		0.73	0.02	0.14	0.01
	35				
Control		36.1	2.6	4.2	37.0
Shade		33.9	2.8	4.4	33.4
LSD 0.05		2.6	0.2	0.3	2.2
$P > F$		0.10	0.05	0.14	0.01

light levels reduced ovule starch levels at 0 and 14 DPA by 4 and 10%, respectively. Ovule glucose and sucrose levels were altered by the light treatments on the last two harvest dates (21 and 35 DPA). The shade treatment reduced sucrose levels in the ovule by 20% at 21 DPA and by 10% at 35 DPA. The opposite response was observed for glucose. Glucose levels from ovules produced under low light conditions were 9% greater than that of the control ovules. Fructose levels in the ovules were not significantly altered by varying the growth light regime.

Whereas cotton producers can receive modest returns for their cottonseed, the lint remains by far the most economically important cotton product. Therefore, correlating environmentally induced alterations in fiber quality with underlying biochemical changes would be beneficial. For the fiber carbohydrates monitored in this study, the effect the lower light regimes produced was similar across genotypes, and therefore, treatment means were averaged across genotypes.

Fiber starch only differed significantly between light regimes at 14 DPA, and in that case there was a strong year $\times$ treatment interaction. In 2 of 3 yr, the shade treatment caused a significant reduction in fiber starch levels (Table 5). In 1995, shade caused a 56% reduction in fiber starch at 14 DPA relative to the control, and in 1997, there was a 47% reduction in fiber starch with the shade treatment. The starch levels did not differ between treatments in 1996 at 14 DPA or at any other harvest date. By 35 DPA, very little starch was detected in the fiber.

Glucose and fructose were the most abundant soluble carbohydrates in the fiber (Fig. 1 and 2). Levels of fiber glucose did not differ between light treatments for any harvest date and that response was consistent every year, consequently only the average across years is shown (Fig. 1). The fructose response to the reduced light regime was different than that exhibited by the other carbohydrates. Whereas the shade treatment had no effect on fiber fructose levels at 14 and 35 DPA, shade actually promoted a 13% increase in the fructose level relative to the control on 21 DPA. This response
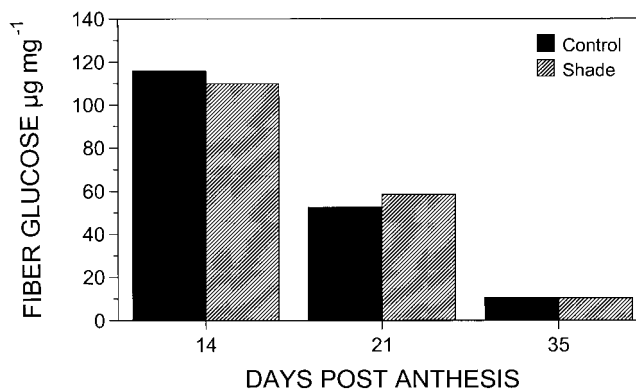

Fig. 1. Fiber glucose levels at various stages of fiber development as affected by light regimes (control = incident sunlight and shade = 70% of incident sunlight), averaged across genotypes and years.

was consistent across years, and only the average across years in shown (Fig. 2).

Very little sucrose was detected in the fiber compared with the other soluble carbohydrates (Table 5), but this low sucrose level relative to the glucose and fructose levels is comparable to that reported by Jaquet et al. (1982). Even at such low levels, sucrose was affected by reducing the light regime. In 2 of 3 yr (1995 and 1997), lowering the light regime had no effect on fiber sucrose level at 14 DPA. In 1996, however, the shade treatment caused a 92% increase in sucrose at that harvest date. At 21 DPA, the low light regime consistently reduced the fiber sucrose levels in every year of the study. On average, the fiber sucrose level at 21 DPA was reduced 33% for plants grown in the low light regime. By 35 DPA, however, there were no longer differences in fiber sucrose between light regimes for any year of the study.

The results from this study indicate that both selected fiber quality traits and fiber carbohydrate levels were reduced in a low light growth regime. Because no differences in carbohydrates were detected on the last sampling date, 35 DPA, the reductions in fiber carbohydrates earlier in development might be considered only a temporary effect. However, this could be a misleading conclusion. These carbohydrates are nonstructural, transient in nature, and serve as substrates for many other biochemical reactions. A reduction in their levels

Table 5. Cotton fiber starch and sucrose concentrations from position one fruit as affected by two light regimes at various stages of development averaged across genotypes.

| Treatment	Days post anthesis	Starch			Sucrose		
		1995	1996	1997	1995	1996	1997
		$\mu g\ mg^{-1}$					
	14						
Control		11.4	8.3	8.2	9.9	11.7	9.3
Shade		5.0	10.6	4.3	9.8	22.4	10.7
LSD 0.05		4.1	4.8	3.7	3.1	8.6	5.6
$P > F$		0.01	0.33	0.04	0.93	0.02	0.61
	21						
Control		8.5	9.9	9.8	23.6	17.6	18.1
Shade		7.6	12.2	8.7	21.0	8.7	11.5
LSD 0.05		3.4	2.3	3.4	2.2	7.8	6.0
$P > F$		0.51	0.13	0.43	0.03	0.03	0.03
	35						
Control		0.5	0.6	0.2	23.1	23.0	25.7
Shade		0.4	0.8	0.4	23.8	20.6	23.1
LSD 0.05		0.3	0.3	0.2	4.0	5.1	6.5
$P > F$		0.49	0.07	0.23	0.77	0.34	0.32
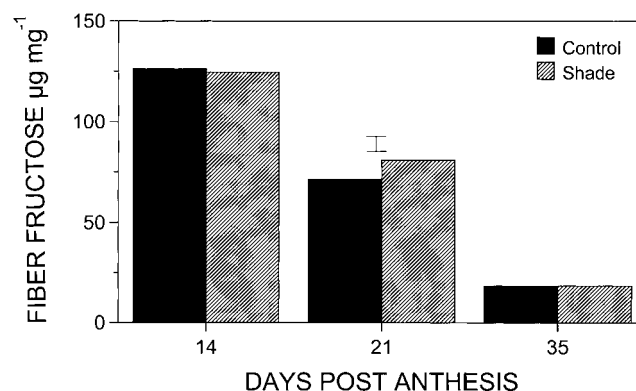
Fig. 2. Fiber fructose levels at various stages of fiber development as affected by light regimes (control = incident sunlight and shade = 70% of incident sunlight), averaged across genotypes and years. The vertical bar denotes the LSD at the 0.05 level.

at anytime during fiber development may alter the way or rate at which these carbohydrates are further metabolized into endpoint fiber structural units or other compounds during that developmental period. This metabolic alteration could further induce permanent changes in fiber development, and subsequently, quality.

Presumably, the reduced carbohydrate levels in the shade fiber were caused by lower photosynthetic rates because of the lower light levels. An alternative explanation could be delayed boll development because of reduced temperatures in the shade, but this explanation is probably not true. Previously, it was shown that boll surface temperatures were no more than 2.5°C or 6% lower in the shade compared with the control (Pettigrew, 1995). These data were collected in the afternoon sun during the hottest period of the growing season, when any temperature differences between the treatments would be at their maximum. This maximum 6% temperature differential between treatments would probably be only a minor effect on carbohydrate concentrations compared with the effect of 30% light reduction. In addition, the fact that all bolls in both the control and shaded treatments opened within 1 to 2 d of each other indicated no appreciable developmental differences.

Prior research has developed a fairly clear time sequence for many fiber developmental events. Elongation of the primary cell wall begins around anthesis, with maximum length occurring at approximately 20 to 25 DPA (DeLanghe, 1985). Secondary cell wall production consists primarily of cellulose being laid down inwardly from the primary cell wall. This synthesis starts at about 15 to 22 DPA and continues until approximately 50 DPA. Micronaire is closely associated with the degree of secondary wall deposition. The development of fiber strength is less clear and presumably more complex. However, Hsieh (1994) reported that the breaking strength of a single cotton fiber reached a maximum at 21 DPA and remained stable throughout the rest of development. No measurements were taken before 21 DPA, so presumably fiber strength was determined sometime between 0 and 21 DPA.

Some of these developmental phases overlap with some of the harvest dates when fiber carbohydrates were measured. Because the shade treatment produced weaker fibers than those produced under control conditions, it is pertinent to examine the trends in fiber carbohydrate level from 0 to 21 DPA (the period when strength is presumably determined). At 14 DPA, low light levels reduced fiber starch for 2 of the 3 yr, even though starch was detected in lower quantities relative to the glucose and fructose levels. Detection of fiber starch in this study stands in contrast with the work of Meinert and Delmer (1977), who were not able to detect starch in cell-wall enriched fractions during fiber development. This apparent contradiction might be because their cell wall purification methodology did not recover noncell wall bound starch or because they used fiber grown in vitro. Furthermore, the presence of starch in the fiber was reported by Ryser (1985) who noted that starch granules were present in plastids of the fiber.

Consistent reductions in fiber sucrose levels at 21

DPA under the low light regime may contribute to the reductions in both fiber strength and micronaire seen in the shade treatment, even though all sucrose levels were quite low. Twenty-one DPA falls near the end of the period when strength is thought to develop, but is in the early stages of secondary cell wall deposition, one of the components determining micronaire. The low levels of fiber sucrose are not surprising in lieu of recent findings concerning the cellulose synthase enzyme complex. The current thinking has a sucrose synthase, operating in the sucrose cleavage mode, closely associated with the cellulose synthase to feed UDP-glucose directly to cellulose synthase (Amor et al., 1995).

Carbohydrate levels fluctuate diurnally, seasonally, developmentally, and in response to various environmental stimuli. Furthermore, previous research has shown that the 30% shade treatment reduced lint yield and number of bolls set by 20% (Pettigrew, 1994). Assuming that the plant only sets the number of bolls that it can successfully supply with a minimum amount assimilates needed for maintaining a reasonably functioning boll, then the retained bolls are partially buffered from large swings in carbohydrate levels when the overall assimilate supply for the plant is limited. If the assimilate supply to a boll drops below a threshold level during the first 2 wk after anthesis, then that boll would probably abscise. However, if the assimilate supply is above the retain threshold level but below the optimum level, then the boll will remain but its fiber quality may suffer. Coupling this buffering capacity with the transient nature of carbohydrates, and the fact that the carbohydrates studied are not structural end-products limits the insights that can be obtained regarding carbohydrate levels and the development of fiber quality. Determining how the activities of various fiber enzymes involved in carbon metabolism and utilization are altered by growth in a low light regime would provide additional insights into the development of fiber strength and micronaire. Nevertheless, monitoring the fiber carbohydrate levels of fiber grown under conditions previously shown to reduce fiber quality further demonstrates the importance of an adequate assimilate supply for ensuring the development of desired fiber quality traits.

In conclusion, growing cotton under reduced light regimes that mimic cloudy conditions results in the production of weaker fiber with reduced micronaire. These low light conditions reduced carbohydrate levels in the subtending leaf, ovule, and fiber. Reductions in starch and sucrose at 14 and 21 DPA, respectively (a developmental period when strength presumably develops), were associated with the production of weaker fiber under shade conditions. The reductions in fiber sucrose at 21 DPA occurred during the period when the secondary cell wall is being deposited and may have contributed to the reduction in micronaire. On the basis of this research, it would appear that any technique (cultural or genetic) that increased the assimilate supply to the developing boll would help to maximize desired fiber quality traits. One caveat to this conclusion is that in the quest for greater yields, breeders have pushed the micronaire of many popular genotypes to the upper

edge of the nonpenalty range for micronaire. If the micronaire genetic maximum for a given genotype were to be above the nonpenalty range, maximizing the boll's assimilate supply could produce negative consequences for producers in those instances.

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